# The development of the NSST within the NCEP GFS/CFS

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Acknowledgements:
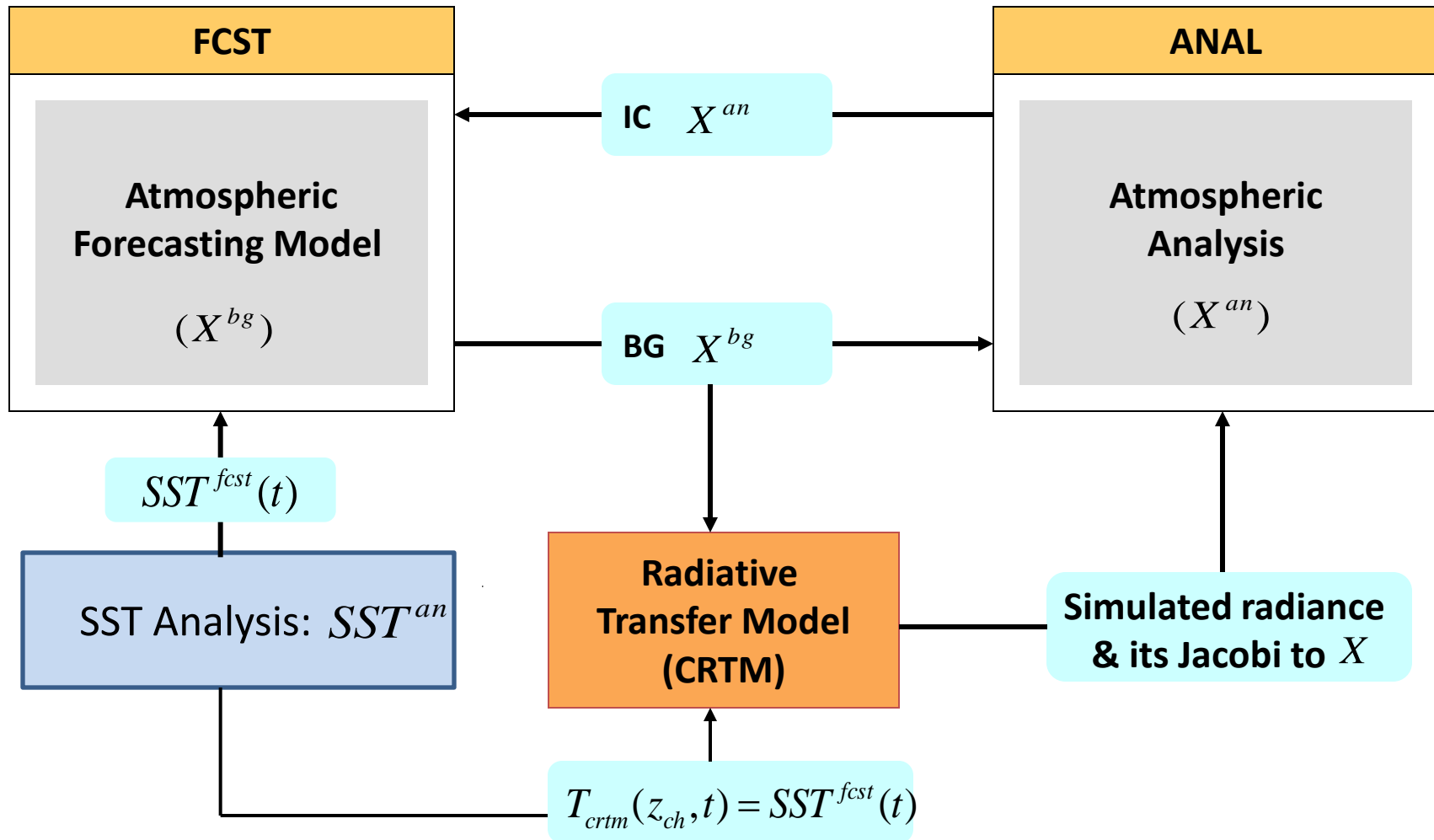
DA, MODEL and More

May 5, 2015

# Outline

- Current ocean (SST) in NWP

- What is NSST (Near-Surface Sea temperature)

- The development of the NSST within the NCEP Global Forecast System(GFS)

- The incorporation of the NSST into the NCEP Climate Forecast System (CFS, scheme/future)
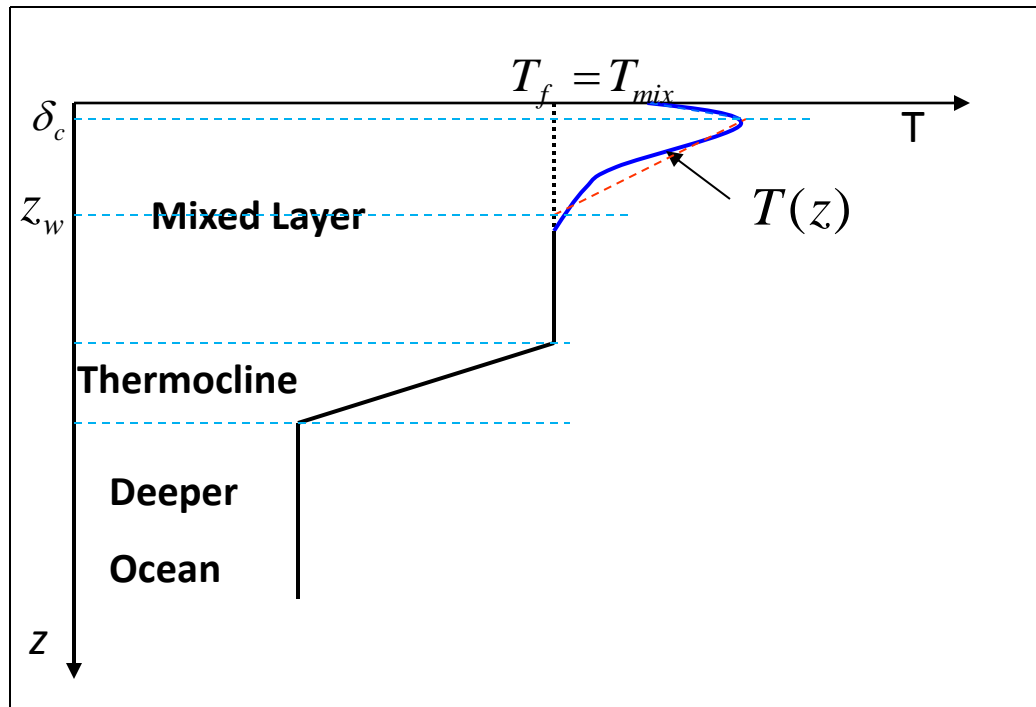
# Current ocean (SST) in the NCEP GFS



$$SST^{fcst}(t) = [SST^{an}(t_0) - SST^{clim}(t_0)]e^{-(t-t_0)/T_{90d}} + SST^{clim}(t)$$

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# A more realistic ocean:
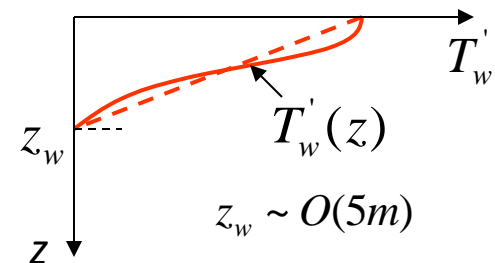## Extending SST to NSST (Near-Surface Sea Temperature)

NSST is a **T-Profile** just below the sea surface.
Here, only the vertical thermal structure due to **diurnal thermocline layer warming**
and **thermal skin layer cooling** is resolved



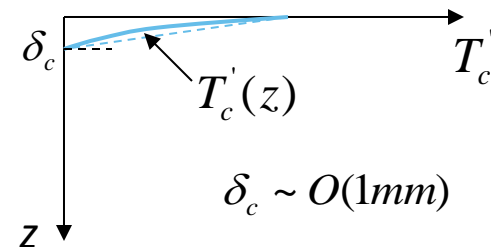Diurnal Warming Profile

$$T_w^{'}(z) = (1 - z/z_w)T_w^{'}(0)$$

$z_w \sim O(5m)$

Skin Layer Cooling Profile

$$T_c^{'}(z) = (1 - z/\delta_c)T_c^{'}(0)$$

$\delta_c \sim O(1mm)$

$$T(z,t) = T_f(z_w, t) + T_w^{'}(z,t) - T_c^{'}(z,t) \quad z \in [0, z_w]$$

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# Scientific basis for the NSST development

- **The more realistic ocean**
  - The inclusion of the diurnal variability with NSST model
- **The use of more observations**
  - All observations available in GSI of NCEP GFS plus **AVHRR, AMSRE** and **in situ sea temperature** (buoys, ships…)
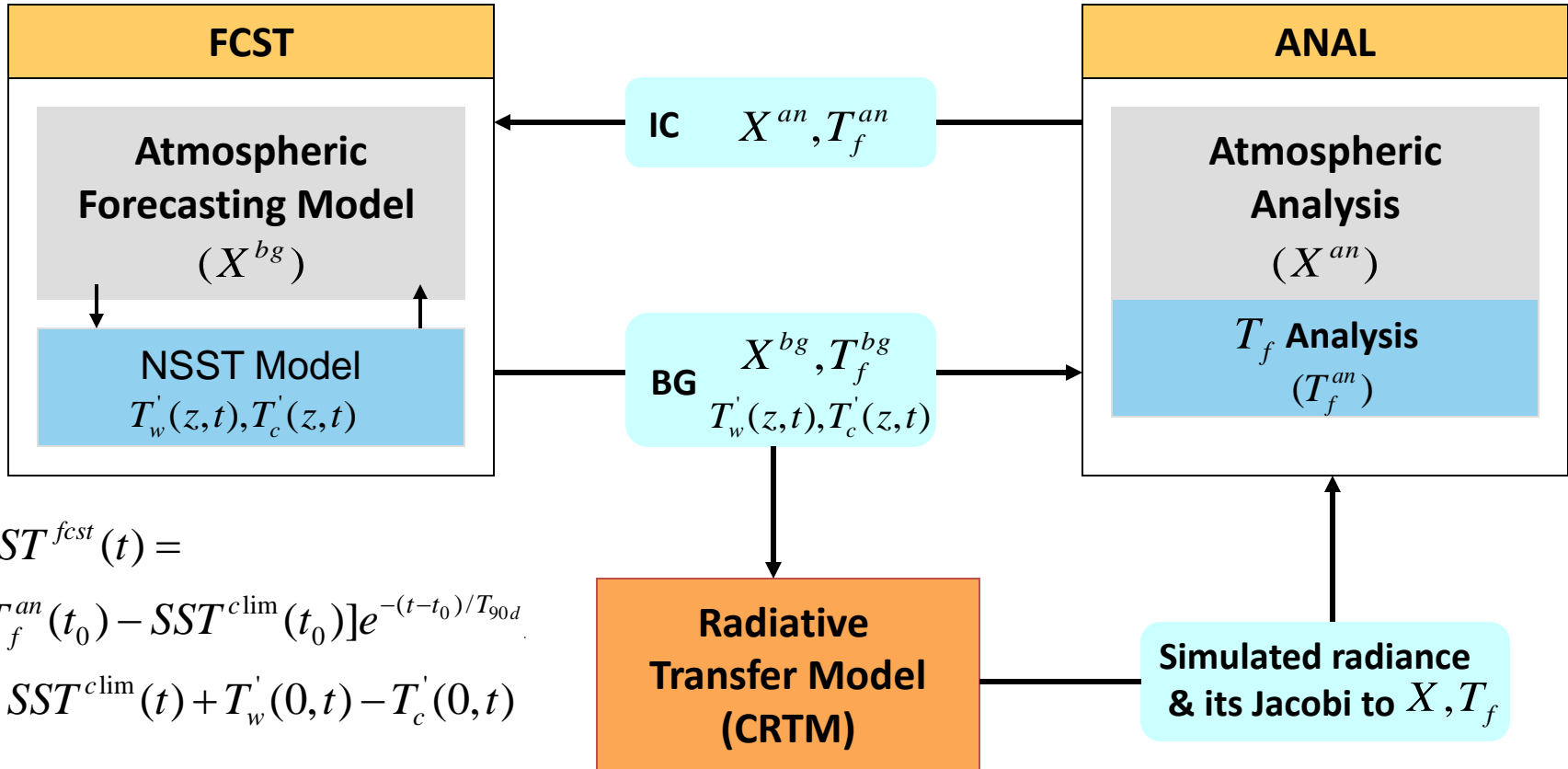- **The more effective use of observations**
  - Direct assimilation to extract the information from the indirect observation more effectively, including satellite and in situ data
- **Coupled data assimilation and prediction**
  - Analysis
    - More consistent initial conditions of the atmosphere-ocean system by minimizing a single cost function
  - Prediction
    - Prognostic SST by the (partially) coupling of atmosphere and ocean

# The NCEP GFS with the NSST



**FCST**

Atmospheric Forecasting Model $(X^{bg})$

NSST Model $T_w^{'}(z,t), T_c^{'}(z,t)$

**IC** $X^{an}, T_f^{an}$

**ANAL**

Atmospheric Analysis $(X^{an})$

$T_f$ Analysis $(T_f^{an})$

**BG** $X^{bg}, T_f^{bg}$ $T_w^{'}(z,t), T_c^{'}(z,t)$

Radiative Transfer Model (CRTM)

Simulated radiance & its Jacobi to $X, T_f$

$$SST^{fcst}(t) =$$
$$[T_f^{an}(t_0) - SST^{c\lim}(t_0)]e^{-(t-t_0)/T_{90d}}$$
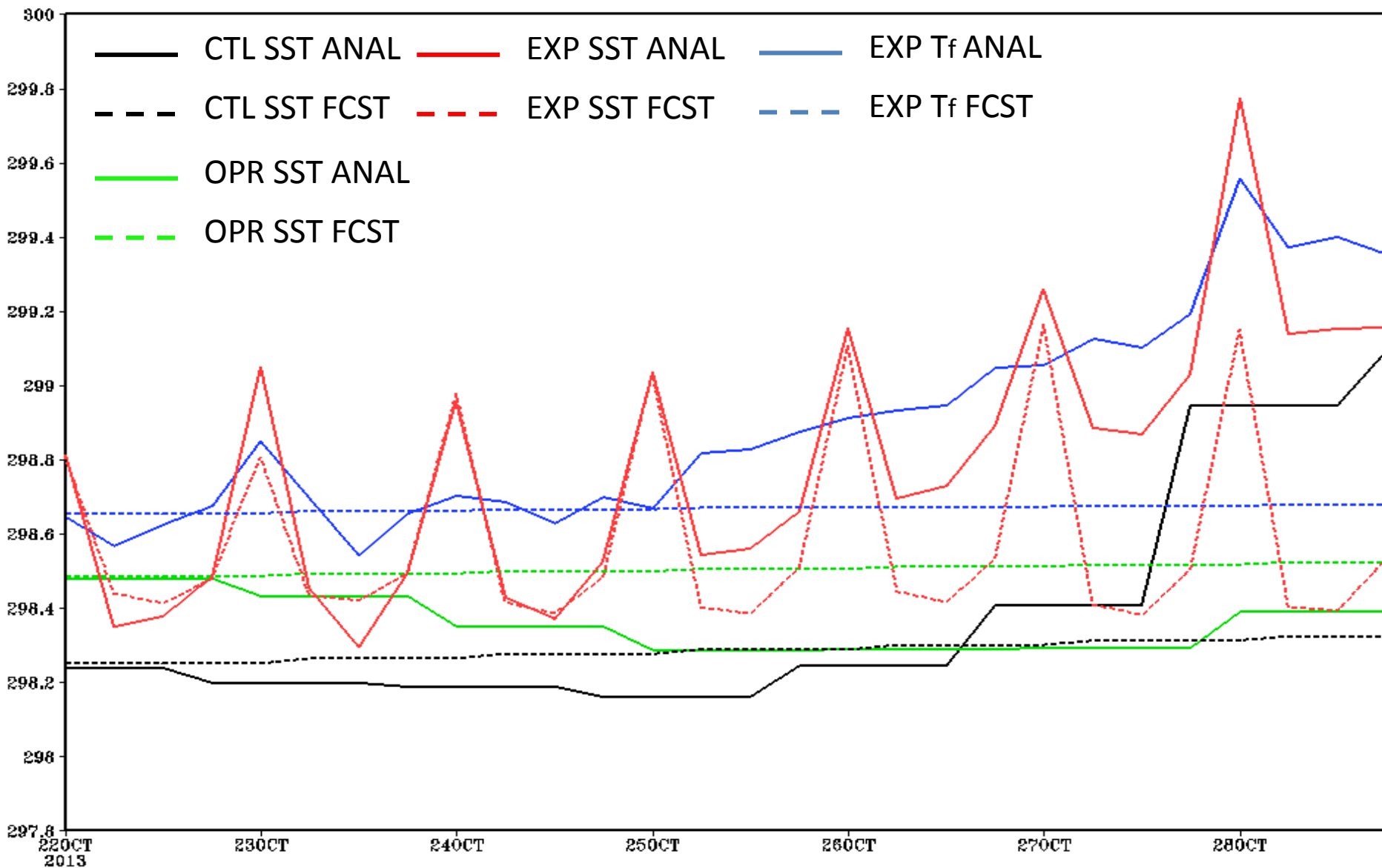$$+ SST^{c\lim}(t) + T_w^{'}(0,t) - T_c^{'}(0,t)$$

$$T_{crtm}(z_{ch}, t) = T^{fcst}(z_{ch}, t)$$

$$T^{fcst}(z,t) = T_f^{bg}(z_w, t) + T_w^{'}(z,t) - T_c^{'}(z,t)$$

Time series of SST/Tf analysis. Area: (141 W – 139 W, 4S – 4N)
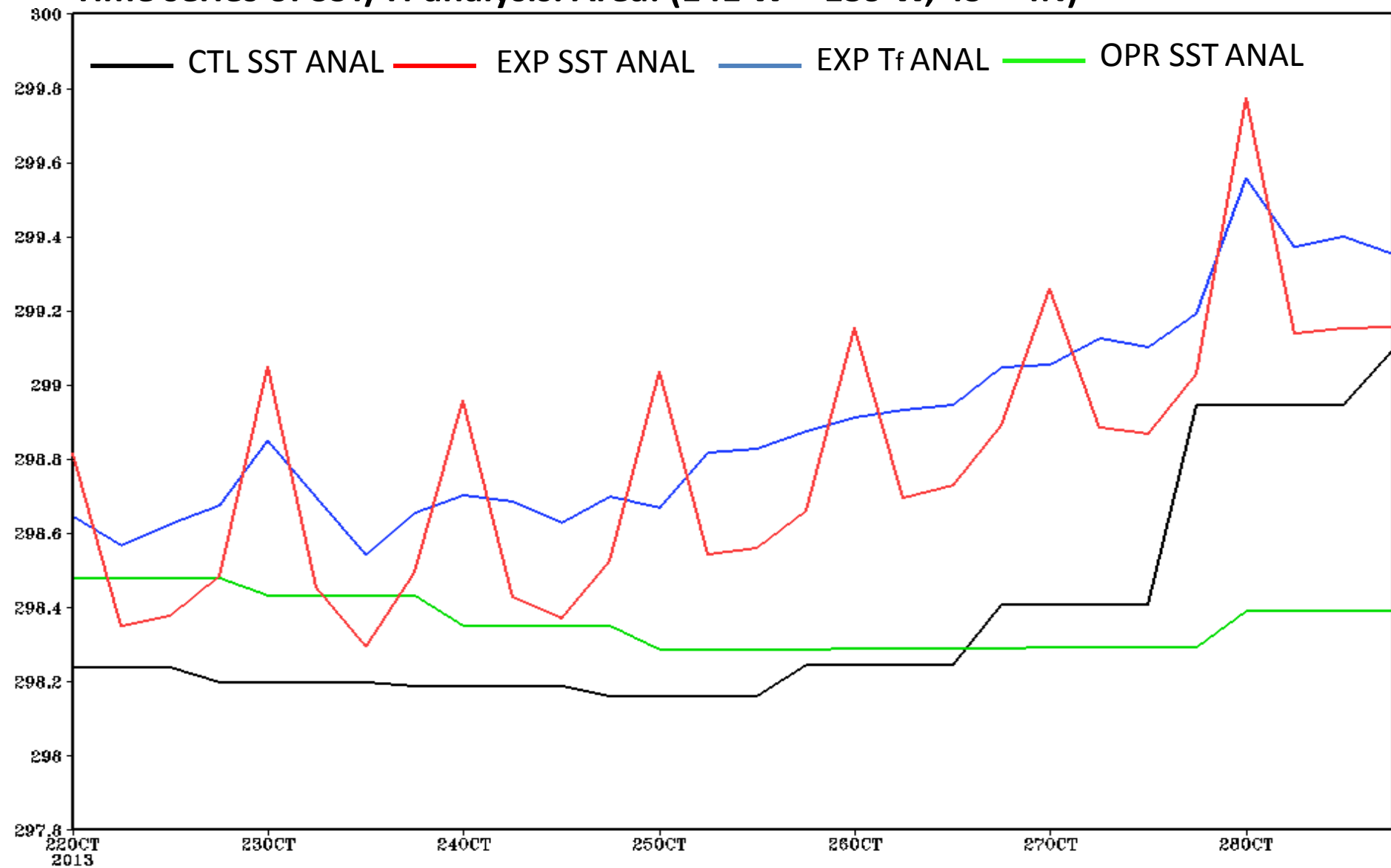
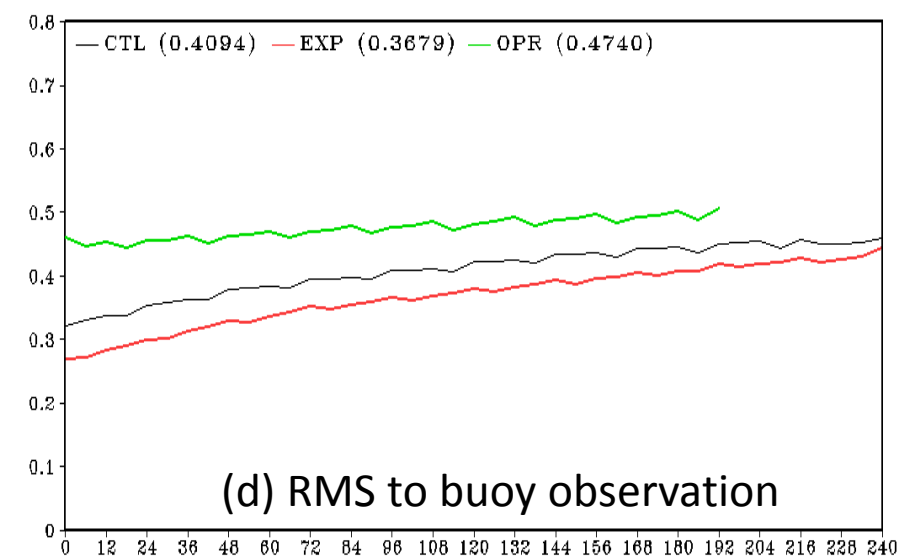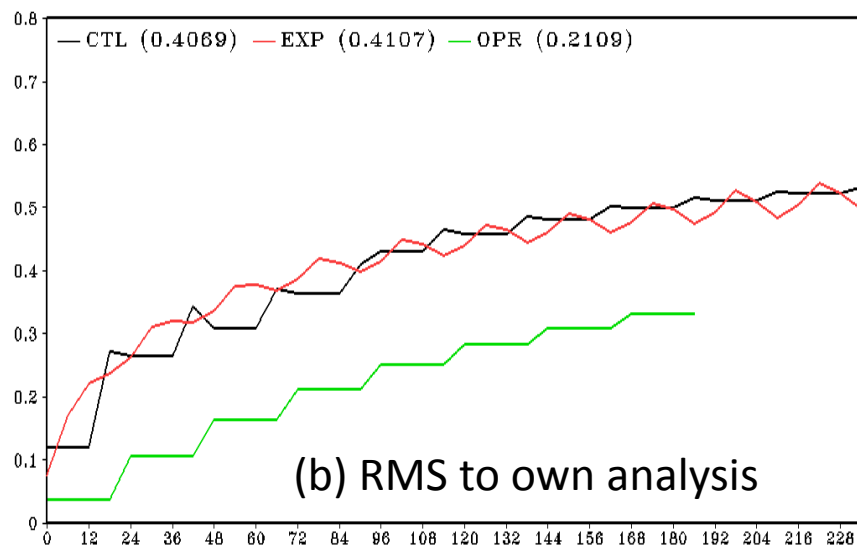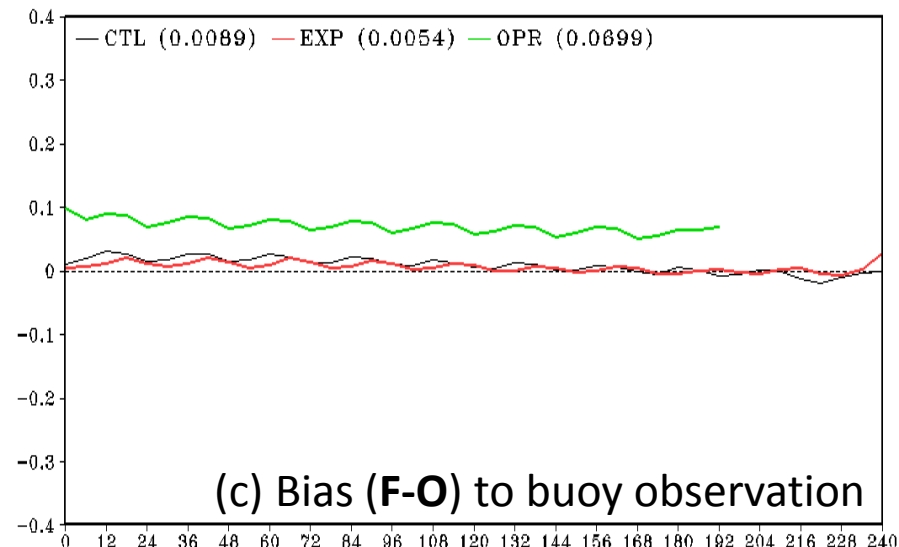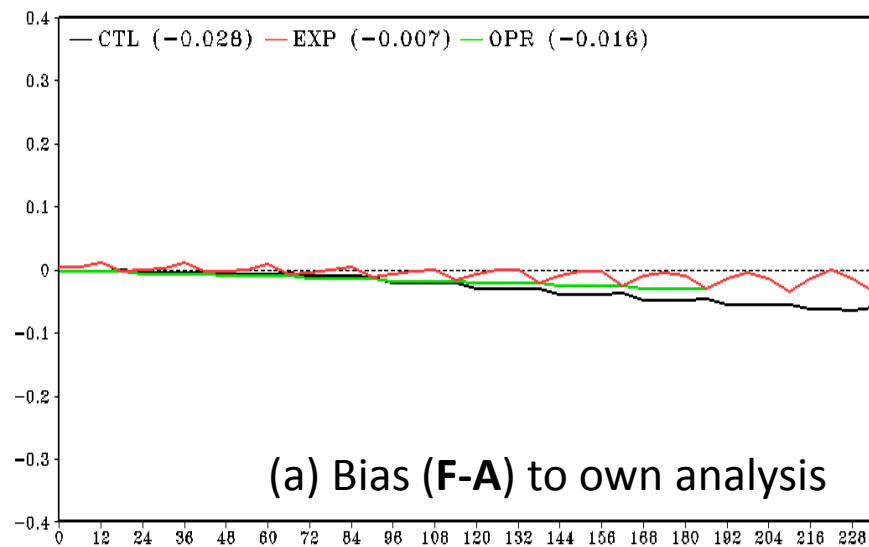Time series of SST/Tf analysis and prediction. Area: (141 W – 139 W, 4S – 4N)

# Verifications

- **Oceanic analysis and prediction**
  - Positive
- **The use of satellite data (O-B)**
  - Slightly Positive
- **Weather Prediction**
  - Neutral for NH and SH, positive for tropics at around 200 mb level, when verified against to the own analysis,
  - Slightly positive when verified against the conventional observations

(a) Bias (**F-A**) to own analysis

CTL (−0.028)   EXP (−0.007)   OPR (−0.016)

(c) Bias (**F-O**) to buoy observation

CTL (0.0089)   EXP (0.0054)   OPR (0.0699)

(b) RMS to own analysis

CTL (0.4069)   EXP (0.4107)   OPR (0.2109)

(d) RMS to buoy observation

CTL (0.4094)   EXP (0.3679)   OPR (0.4740)

**The verification of predicted SST, starting from 00Z, November 2013, Global.**

**RTG SST**        (**CTL,** the current operational, RTG daily analysis)

**NSST SST**       (**EXP,** NSST 6-hourly analysis)

**Reynolds SST** (**OPR,** the previous operational, OI weekly analysis)

# Incorporation of the NSST into the NCEP GFS

- Issues in the NSST

- Issues in the NCEP CFS

- The relationship between the oceanic model first layer temperature and SST
  - Through the foundation temperature and NSST T-Profile

- The combination of the NSST and the NCEP CFS

# Issues in the NSST within the GFS

- At the prediction step, $T_f$ steady since no its forward model

- At the analysis step, the covariance between $T_f$ and atmospheric analysis variables is not included yet

# Issues in the current NCEP CFS

- Mismatch between the first layer temperature ($\overline{T}_{z_1}$) and other variables of OGCM

  - An independent SST analysis is used as the first layer temperature ($\overline{T}_{z_1}$) of OGCM

- Too weak SST diurnal variability due to the coarse vertical resolution

- The first layer's temperature, $\overline{T}_{z_1}$, which is not SST but is used as SST ($z_1 = 10m$ in the current CFS)

# The Relation between the oceanic model first layer temperature $(\overline{T}_{z_1})$ and foundation temperature $(T_f)$

- The relationship among $T(z), T_f, T_w^{'}, T_c^{'}$

$$T(z) = T_f + T_w^{'}(z) - T_c^{'}(z)$$

- The relation between $\overline{T}_{z_1}$ and $T_f$ can be derived by integrating the above equation from *z=0* to *z=z1*

$$\overline{T}_{z_1} = T_f + (1/z_1) \int_0^{z_1} [T_w^{'}(z) - T_c^{'}(z)] dz$$

delTemp 10m average
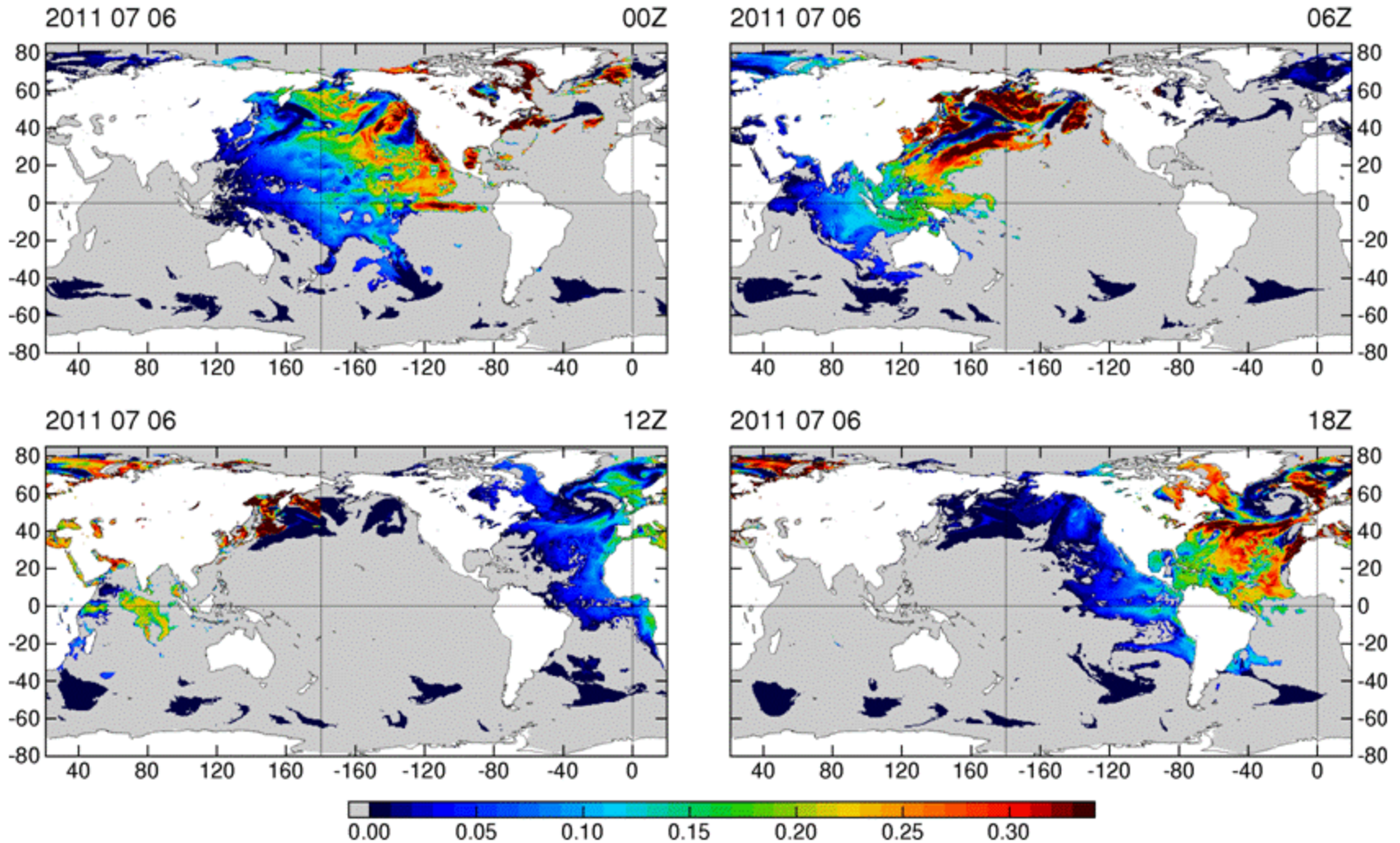
$$\overline{T}_{z_1} - T_f = \frac{1}{z_1} \int_0^{z_1} [T_w^{'}(z) - T_c^{'}(z)]dz$$

# The combination of the NSST and the NCEP CFS

- **Coupled initialization**
  - Consistent $\overline{T}_{z_1}$ with the other oceanic variables

$$\overline{T}_{z_1}^{an}(t) = T_f^{an}(t) + (1/z_1)\int_0^{z_1}[T_w^{'}(z,t) - T_c^{'}(z,t)]dz$$

- **Coupled prediction**
  - Evolving $T_f$

$$T_f(t) = \overline{T}_{z_1}(t) - (1/z_1)\int_0^{z_1}[T_w^{'}(z,t) - T_c^{'}(z,t)]dz$$
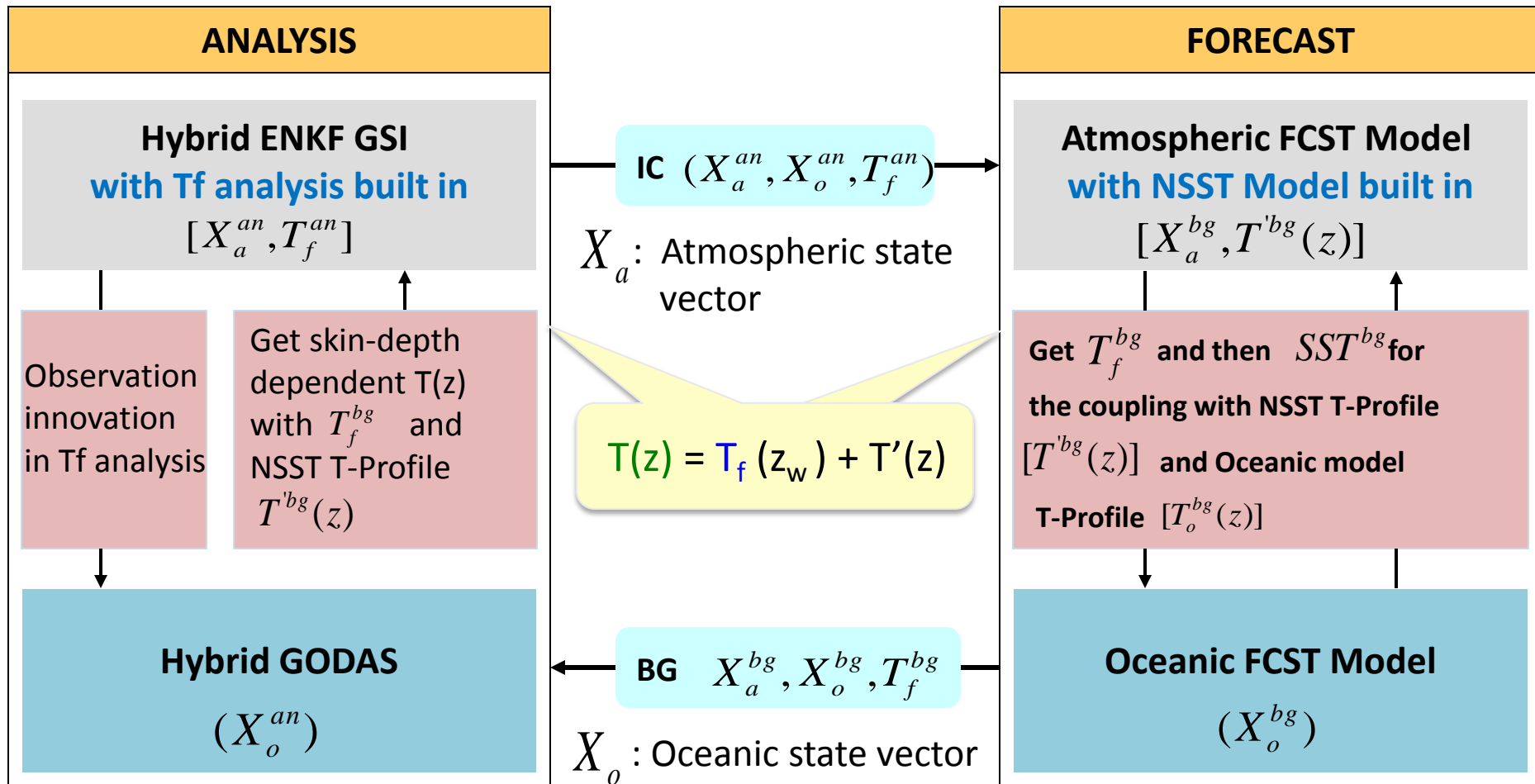
  - Real SST instead of $\overline{T}_{z_1}$ used at the interface

$$SST^{fcst}(t) = T_f(t) + T_w^{'}(0,t) - T_c^{'}(0,t)$$

# The NCEP CFS with the NSST
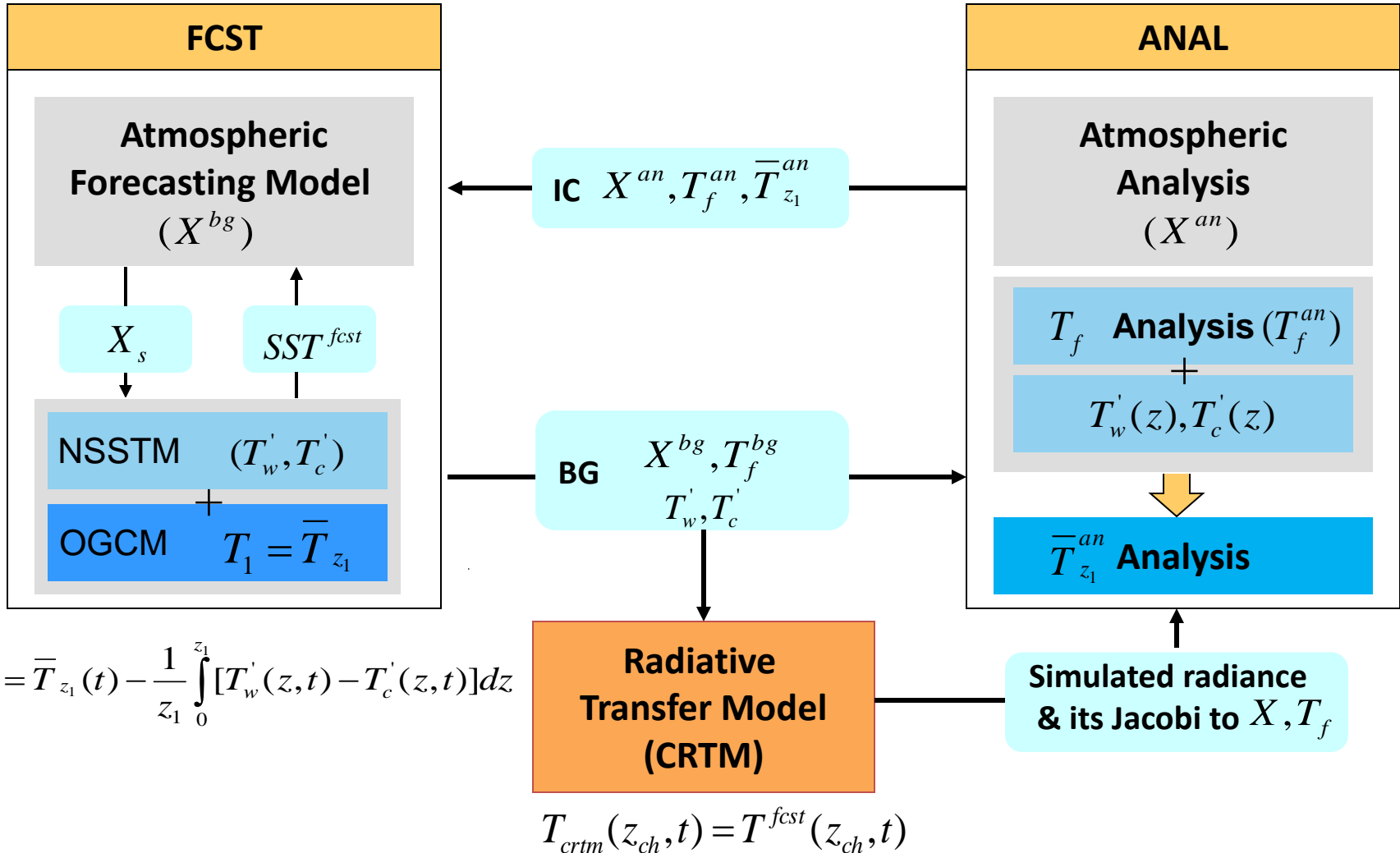
# Incorporation of the NSST into an air-sea coupled data assimilation and prediction system (**Reanalysis**)

| ANALYSIS | FORECAST |
|---|---|

**Hybrid ENKF GSI**
**with Tf analysis built in**
$$[X_a^{an}, T_f^{an}]$$

IC $(X_a^{an}, X_o^{an}, T_f^{an})$

**Atmospheric FCST Model**
**with NSST Model built in**
$$[X_a^{bg}, T'^{bg}(z)]$$

$X_a$: Atmospheric state vector

Observation innovation in Tf analysis

Get skin-depth dependent T(z) with $T_f^{bg}$ and NSST T-Profile $T'^{bg}(z)$

Get $T_f^{bg}$ and then $SST^{bg}$ for the coupling with NSST T-Profile $[T'^{bg}(z)]$ and Oceanic model T-Profile $[T_o^{bg}(z)]$

T(z) = T$_f$ (z$_w$) + T'(z)

**Hybrid GODAS**
$$(X_o^{an})$$

BG $X_a^{bg}, X_o^{bg}, T_f^{bg}$

**Oceanic FCST Model**
$$(X_o^{bg})$$

$X_o$ : Oceanic state vector

NSST algorithm is part of both the analysis and forecast system. In the analysis, the NSST provides an analysis of the the interfacial temperature ("SST") in the hybrid ENKF GSI using satellite radiances. In the forecast, the NSST provides the interfacial temperature (SST) in the free, coupled forecast instead of the temperature at 5-meter depth that is predicted by the ocean model.

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# Summary

- The NSST has been developed within the NCEP GFS and has shown positive impact on the analysis and prediction of the ocean and atmosphere in weather prediction time scale
- A scheme has been proposed on the incorporation of the NSST into the NCEP GFS in order to resolve the issues/problems in the NSST and the NCEP CFS
  - A fully coupled data assimilation and prediction system for both weather and climate prediction